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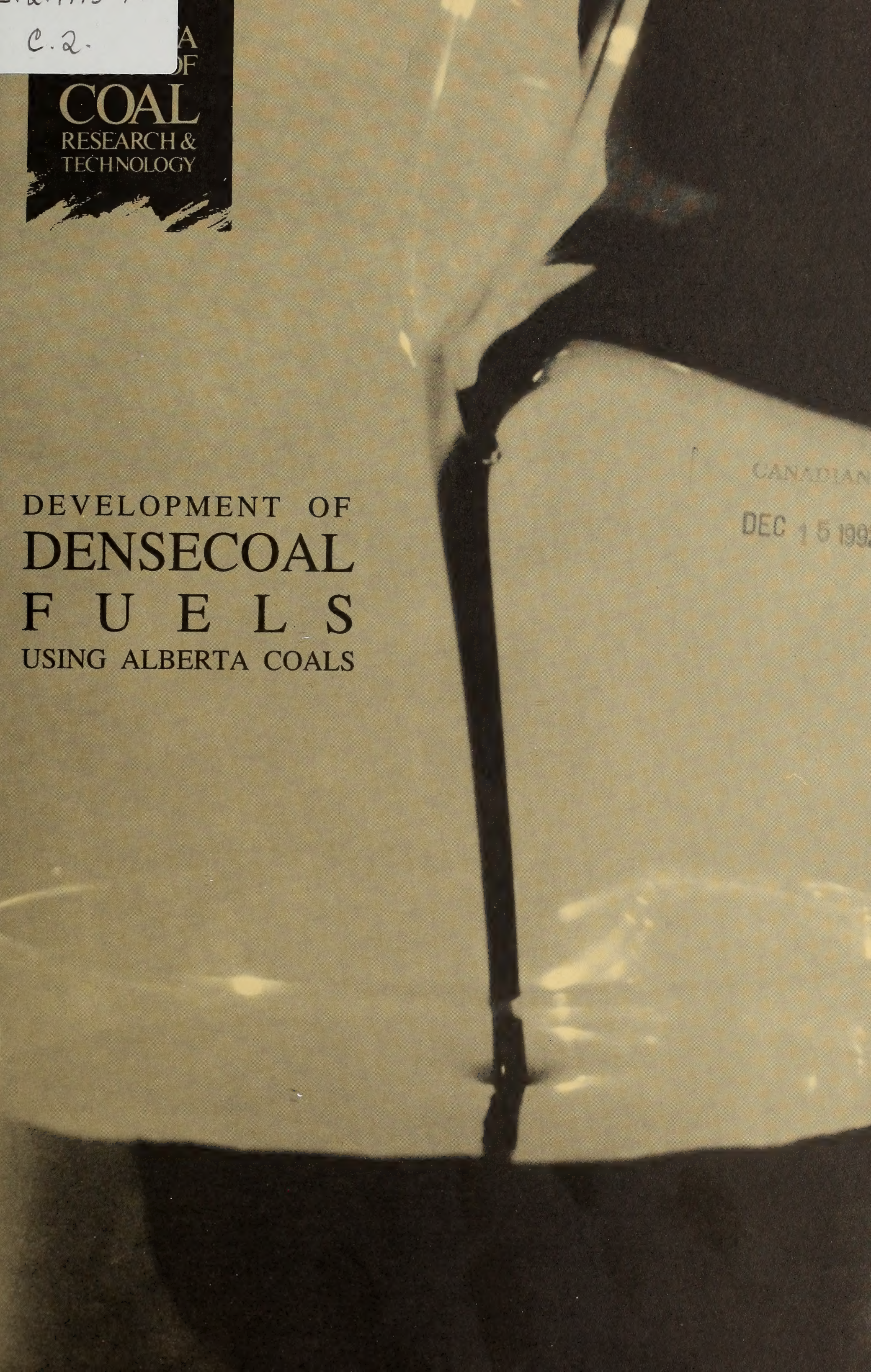


DEVELOPMENT OF

DENSECOAL FUELS

USING ALBERTA COALS

ALBERTA OFFICE OF COAL RESEARCH & TECHNOLOGY

DEVELOPMENT OF DENSECOAL FUELS USING ALBERTA COALS

Foreword

Alberta coals contain much less sulphur than coals from other coal-producing regions of the world. This makes Alberta coals highly desirable in Asian and central Canadian markets. Because reaching these markets involves long-distance rail haul from Alberta's coal mines to ocean terminals on the west coast of Canada, or to Great Lakes terminals in Ontario, the overland transportation costs are significant. This makes it difficult for Alberta's coal producers to compete in these markets.

With the development of coal-water slurry fuels that can be pumped through pipelines and have combustion characteristics similar to fuel oil, an opportunity has arisen to provide an alternative method for transporting Alberta coals to distant markets and for coal to penetrate some of the existing fuel-oil markets.

Therefore, the Alberta and Canadian governments, along with industry, contributed financial support over several years to investigate the suitability of using Alberta coals in one proprietary coal-water fuel system – DENSECOAL – and then burning the resulting slurries in utility boilers.

The study showed that it is both technically and economically feasible to make DENSECOAL from Alberta coals, and there should be no technical impediments to operating such systems at a commercial scale. It is necessary, however, to carry out the large-scale tests necessary to bring cost estimates to the "Class A" level so that commercial commitments can be made.

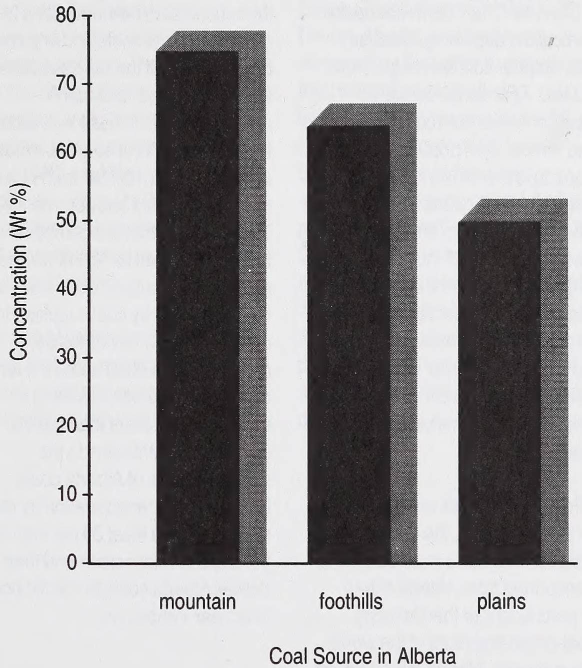
The purpose of this publication is to describe the advancements that have been made thus far and to encourage financial participation in the next round of testing. This should be especially relevant to those parties who are interested in pursuing the delivery of Canadian coal slurries to Asia as a commercial venture.

Background

For as long as coal has been used as a fuel, it has been necessary to handle and burn it in a solid form, but now this limitation no longer applies. Today, the world's most abundant fossil fuel can be made into combustible coal-water slurries that resemble fuel oil in appearance and behaviour. This ability of coal to be used as a liquid can significantly reduce the costs of converting oil-fired power plants to low-cost coal.

Most of the coal-water slurry fuels (CWS) that have been developed in recent years are designed for stable storage over extended periods of time. This requires the use of certain chemicals to achieve the desired static stability, but their expense contributes to the cost of making coal-water fuels. While these stabilized slurries can be transported in tankers, their high viscosity makes it impractical to pump them farther than the distance from a tank farm to a boiler. This approach overlooks a significant cost advantage offered by CWS, namely the ability to be transported in a pipeline. Because macromolecular stabilizers and surfactants are used in statically stable CWS, these molecules could be destroyed by internal friction during pipeline transport. This would result in less-stable suspensions. Furthermore, any attempt to pump these slurries over long distances would result in high operating and investment costs caused by the high viscosity of the fluid and large pressure losses.

Typical Maximum Coal Concentration in DENSECOAL Mixtures



A different approach to this problem was taken by Salzgitter Anlagenbau of Salzgitter, Germany. Their proprietary process, called DENSECOAL, was designed from the beginning to allow CWS to be pumped long distances through a pipeline. To achieve this, both the dynamic stability and the dynamic viscosity of the slurries became the most important criteria, rather than the static stability. The lower viscosity of DENSECOAL slurries permits them to be produced thousands of kilometres from the ultimate customer and then be moved to the customer by pipeline or a combination of pipeline and ship, rail or truck transport.

Studies by Salzgitter have shown that DENSECOAL having a coal solids content ranging from 65 to 75 weight per cent can be produced from coal that ranges across the entire spectrum of coal rank, and it can also be made from charcoal and petroleum coke. This combination of characteristics – applicable to a wide range of coals and capable of moving coal long distances – is especially relevant to the coal industry in Alberta, Canada.

Alberta is the largest producer and the second largest exporter of coal in Canada. Coals from Alberta are particularly appealing because their sulphur content ranges from 0.2 to 0.7 per cent. Alberta's location inland from coastal ports and remote from populous central Canada is a disadvantage, however. This means that bituminous thermal and metallurgical coals must be shipped long distances to market. Currently, this involves rail transportation to west coast ports for transshipment to Asia, or rail haul to Thunder Bay, followed by shipment in a Great Lakes vessel to markets in southern Ontario.

While Alberta coals are desired in these markets, the overland distance that coals must be transported from Alberta mines to ports is longer than in many coal-producing parts of the world. For example, Alberta mines, which supply coal to Japan and Korea, are 1 000 to 1 100 km inland from west coast ports. They are also up to 2 350 km west of coal terminals at Thunder Bay, Ontario. This compares with only 260 km from coal mines to ports in Queensland, Australia, and 400 km from mines in Ohio and Pennsylvania to the Great Lakes near Toronto.

Over the past four decades, Canada's railway companies have introduced several innovations to reduce rail-haul costs and improve the efficiency of the rail transportation system. The "unit train" represents one of these innovations. It allows 10 000 t of coal to be moved at one time in a 100-car train that is dedicated to only one commodity. The payloads that are carried on unit trains are moved for tonne-kilometre rates that are substantially less than those charged by coal suppliers in other countries. Nonetheless, nothing can be done about the length of the haul distance, resulting in transportation costs that make a significant contribution to the delivered costs of Alberta coals. For example, transportation by rail accounts for at least 35 per cent of all the costs to mine, clean and then deliver Alberta coals to Pacific ports in or near Vancouver.

Lowering these delivery costs and maintaining the quality of Alberta coals are essential if Alberta coal producers are to become more competitive with American suppliers for the Ontario market, and with suppliers from several countries for Asia-Pacific markets.

Therefore, the Alberta government and Alberta coal producers have undertaken several research projects during the past 10 years to investigate the feasibility of using pipelines to transport coal to markets. In recent years, this research activity has been focused on the DENSECOAL process.

Initial Slurry Testing

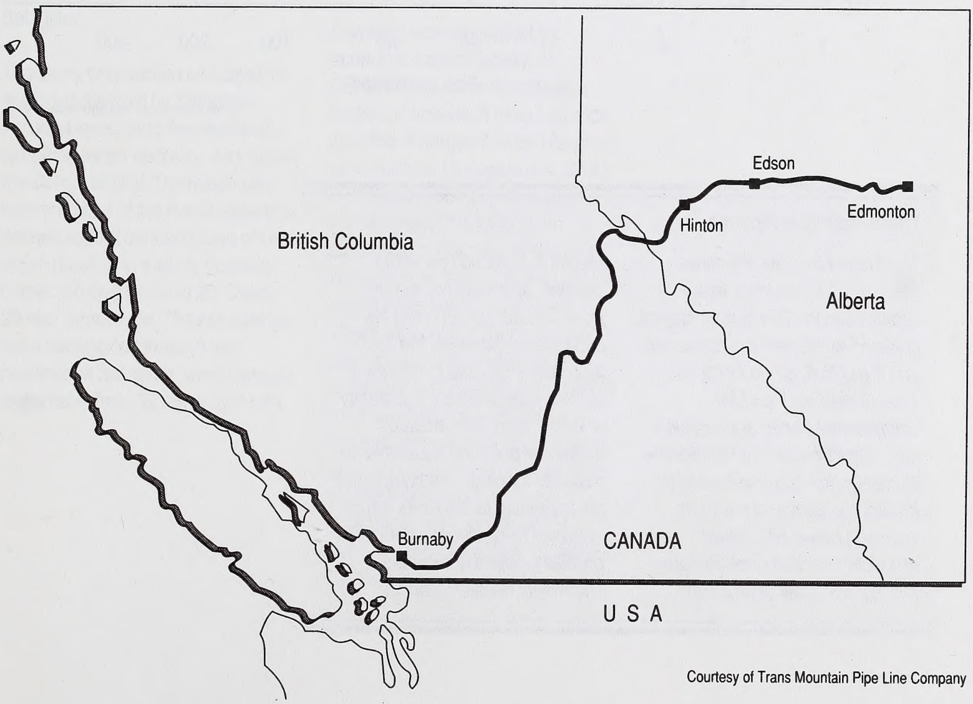
A multi-year, Can $1.65 million project was carried out collaboratively under the umbrella of the Canada-Federal Republic of Germany Science and Technology Agreement, which encourages technology sharing between the two countries.

An investigation was made of the technical and economic feasibility of producing, transporting by pipeline and burning a coal-water fuel made from Alberta coals using Salzgitter's DENSECOAL process.

At the outset, it was assumed that the only economical way to transport DENSECOAL from Alberta to west coast ports was to use spare capacity on the Trans Mountain Pipeline rather than construct a new, dedicated pipeline. Therefore, one of the objectives of the initial pipeline testing that was carried out by Salzgitter was to make certain that a stable CWS could be produced which has a viscosity that is approximately the same as that of the heavy oil carried in the Trans Mountain Pipeline.

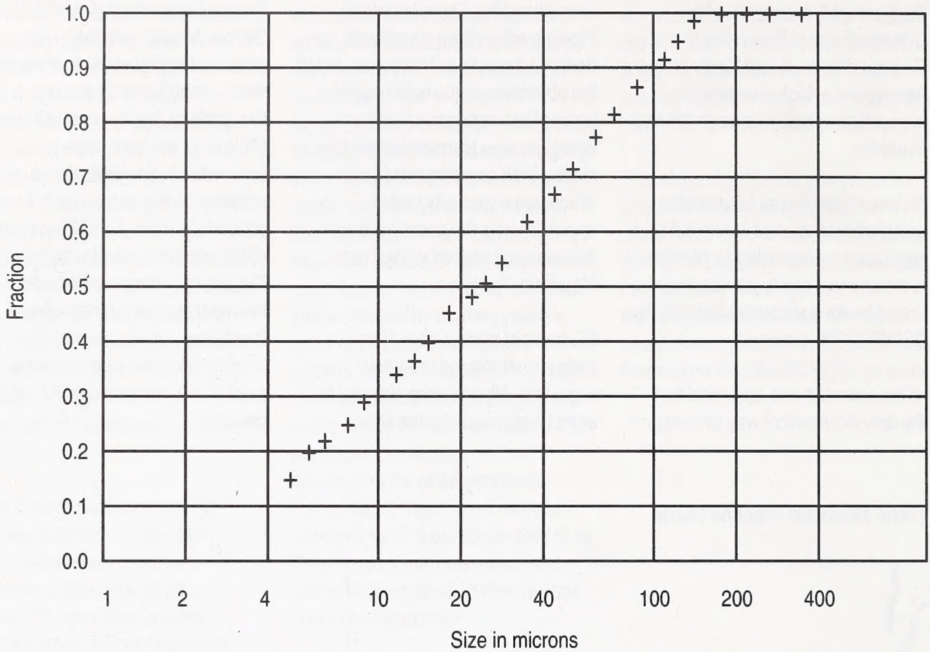
Six coals of various rank from the plains, foothills and mountain regions of Alberta were cleaned to eight per cent ash by the Coal Research Laboratories of the Canada Centre for Mineral and Energy Technology (CANMET) in Devon, Alberta, and then were screened by Salzgitter to determine their suitability for producing fine-grained, highly-concentrated (70 weight per cent solids) coal-water fuels. While these screening tests showed that it was possible to make CWS from all these coals, medium-volatile coals from the mountain region of Alberta made the most suitable slurries. From these coals, it was possible to produce stable suspensions having a solids concentration of 70 weight per cent.

Trans Mountain Pipeline Route



Courtesy of Trans Mountain Pipe Line Company

DENSECOAL CWS Particle Size Distribution



Data courtesy of Salzgitter Anlagenbau

Trans Mountain Pipeline

The Trans Mountain Pipeline, which is 1 146 km long, was constructed in 1954 to ship Alberta crude oil to markets in Vancouver and the U.S.A. Since 1973, the Trans Mountain Pipe Line Company has been aggressively pursuing new uses for the pipeline. Currently, the pipeline is used to transport a variety of products, including heavy oil, refined products and methanol. Because the high viscosity of heavy oil results in reduced flow in the pipeline, and heavy oil exports from Canada's west coast are expected to increase, the Trans Mountain Pipe Line Company is currently expanding the capacity of the system. This includes additional pumping capacity and mainline looping. The company is also planning to seek regulatory approval to construct a second, parallel pipeline to increase shipments of clean product.

Large-Scale Slurry and Combustion Tests

Slurry Testing

Following the initial screening tests by Salzgitter, a medium-volatile and a high-volatile bituminous coal were selected for larger-scale slurry production. Once again, coal samples were beneficiated by CANMET to eight per cent ash, and 10-tonne slurry samples were prepared by Salzgitter. One slurry comprised only the medium-volatile coal (it eventually became known as DENSECOAL-P), while the other was a blend of the two coal types. Five tonnes of each slurry were delivered to the CANMET Energy Research Laboratories at Bells Corners (near Ottawa), Ontario for combustion tests, while pipeline and transportation stability tests were performed on the remainder by Salzgitter.

The slurry preparation and pipeline testing carried out by Salzgitter included measuring the effects of temperature on viscosity, and testing the slurry stability. The maximum concentration of the two slurries was defined as that concentration of coal which resulted in a slurry viscosity below 350 centipoise at 20°C and 20 sec^{-1} shear rate. The two slurries were transported through test pipelines at Salzgitter, which ranged in diameter from 32 mm to 207 mm.

It was concluded that both slurries exhibited stable behaviour and they could be pumped long distances. For these dynamically stable CWSs, it is essential to use agitators, such as tank stirrers, or pumps for recirculation. It was also found that resuspension is possible after a pipeline has been shut down, and that no other difficulties are caused when a pipeline is re-started after a shutdown. This is consistent with experience gained from moving heterogeneous suspensions of solids, such as iron ore, coal and bauxite. The best known example of a commercial-scale pipeline used for transporting coarse coal slurries is the Black Mesa Pipeline. It extends 439 km across Arizona and has been carrying slurried coal from a mine to a power plant since 1970.

A system was developed for economic transshipment of DENSECOAL over inland water bodies or oceans. It uses tugboats coupled to barges that can function as in-harbour storage tanks. Small recirculating pumps are required to keep the DENSECOAL in suspension. The pumps should be capable of recirculating the total load over a period of 12 to 24 hours. These recirculating pumps may be used for unloading where a low unloading rate is adequate, such as when the barge is used for local storage. Barges may also load and unload in a star-form configuration at single-point buoys. Barge washwater may be burned by overfire injection or by fluidized-bed combustion.

Also, powdered P coal and the chemicals required to make it into a slurry were sent to Idemitsu Kosan Co. Ltd. in Japan to compare the slurrying characteristics of the medium-volatile bituminous coal with others tested previously by this company. A sample of DENSECOAL-P slurry was also sent to Idemitsu for testing. Idemitsu found that the slurry they made had a higher solids content then DENSECOAL-P, and it was also more viscous and less stable.

Properties of Coal Used to Make DENSECOAL-P

	weight per cent
Moisture	1.08
Ash*	7.34
Volatiles*	26.1
Sulphur*	0.20
Nitrogen*	1.19
Hydrogen*	4.67
Carbon*	81.12

Heating Value	higher*	33 268 kJ/kg
	lower	32 213 kJ/kg

Density*	1 377 kg/m^3

Ash Analysis

Fe	2.77
Mn	0.01
P	0.30
S	1.50
SiO_2	53.81
Al_2O_3	26.11
CaO	6.35
MgO	1.67
TiO_2	1.13
Na_2O	1.24
K_2O	0.39
Zn	1.33

*dry basis

DENSECOAL-P Properties

Coal Concentration	~70%
Water Concentration	~ 29.3%
Additive Concentration	~ 0.7 %

Variation of Apparent Viscosity with Temperature*

°C	mPa
5	505
10	360
15	280
20	230
25	185
30	165

Particle Size Distribution

100 per cent	–0.20 mm
70 per cent	–0.05 mm
50 per cent	–0.03 mm
25 per cent	–0.01 mm

Density	1.22 kg/L
Calorific Value	22 MJ/kg

*shear rate 100 sec^{-1} and 20°C

Combustion

The initial combustion tests carried out by CANMET were unsatisfactory, primarily because the atomizers used during the test did not produce acceptable sprays. This was partly attributed to settling of the DENSECOAL during shipping from Germany to Bells Corners. It was suggested that changes be made to improve the spray quality of the slurries, and a higher proportion of more volatile coal be incorporated into the coal blend.

The combustion program was redesigned and provision was made to keep the slurries agitated during transport to avoid settling. This time, pilot-scale combustion testing was performed by the Energy and Environmental Research Corporation (EERC) in Irvine, California, and only the slurry made from the medium-volatile bituminous coal (DENSECOAL-P) was tested. A Y-jet atomizer employing an air-to-fuel ratio of 0.40 was used. Computer modelling, based on pulverized coal combustion, showed that it might be necessary to "derate" boiler performance when DENSECOAL-P was used relative to that when fuel oil was used. The test results, however, were not regarded as being particularly successful, and it was thought the poor results were caused by the Y-jet atomizer.

CWS Combustion

Potential sources of difficulties arising from the combustion of CWS in a boiler, particularly one designed to burn oil, include the following:

1) *slurry inhomogeneity;*
2) *inconsistency of viscosity;*
3) *phase separation caused by settling;*
4) *phase separation caused by evaporation;*
5) *ignition instability;*
6) *flame configuration;*
7) *bottom-ash accumulation;*
8) *slagging and fouling by ash;*
9) *boiler tube erosion by ash; and*
10) *ash mass, volume and carbon content.*

Typically, items 1 to 5 are less critical in larger installations. A properly designed burner, especially the atomizer, is critical for items 5 to 9. Items 7 to 10 affect both the operation and the economics of the boiler.

CANMET has tested many slurry fuels with respect to these 10 criteria. Tests on fuels containing various levels of ash showed that an excessive and uneconomic amount of soot blowing was required for fuels with more than eight per cent ash, even though soot blowing is effective in removing ash from superheater or reheater tubes. These results are consistent with small-scale tests done in Britain on 10 CWSs. From the combined experience of all this testing, it was found that the ash formed during the combustion of CWS behaves more benignly in a boiler than that formed during the conventional combustion of pulverized parent coals in air.

From CANMET's experience, the combustion of a CWS containing four per cent ash caused fewer boiler maintenance problems – in terms of cleanliness in the furnace and of heat exchange surfaces – than did residual oil in a small utility boiler having no bottom-ash removal capabilities and only 26 mm spacing between the superheater tubes. No slagging occurred despite the high iron content of the ash. Soot blowing was effective in removing accreted ash. The bottom-ash accumulation was negligible. Tube erosion in convection passes was imperceptible at the point of maximum gas pass velocity, and virtually all the ash was collected as flyash in the baghouse. Use of this CWS did not diminish the maximum output of the boiler.

Therefore, the Nova Scotia Research Foundation Corporation in Dartmouth was contracted to conduct atomization tests on a DENSECOAL-P slurry using both a Y-jet atomizer and an internal mix prefilming atomizer developed by the National Research Council of Canada. It was found that both atomizers performed well, but that the particle size distribution from each atomizer was quite different.

Subsequently, two samples of DENSECOAL-P underwent large-scale combustion testing by CANMET at the Energy Research Laboratories. A flame tunnel furnace was used for these tests. This furnace, which has a 1-m diameter and is 4.25 m long, is instrumented with 28 calorimeters that enable heat absorption measurements to be taken at 15-cm intervals along the length of the furnace. The furnace was used to evaluate the following:

- the effect of combustion air temperature on the combustion efficiency and carbon burnout characteristics;
- ignition stability;
- flame shape and size;
- sparkler formation; and
- carbon in the flyash.

It was observed that when proper atomization and mixing with combustion air were used in the burner, DENSECOAL can be burned in a furnace/boiler combination that is substantially smaller than that required to burn the parent coal as a pulverized suspension. It was concluded that the provision of adequate soot blowing and flyash management systems should permit DENSECOAL which contains eight per cent ash to be burned satisfactorily in a boiler designed to burn poor quality residual oil. Of equal importance, this series of combustion tests showed that the extent of derating was small.

Burner Technology for CWS

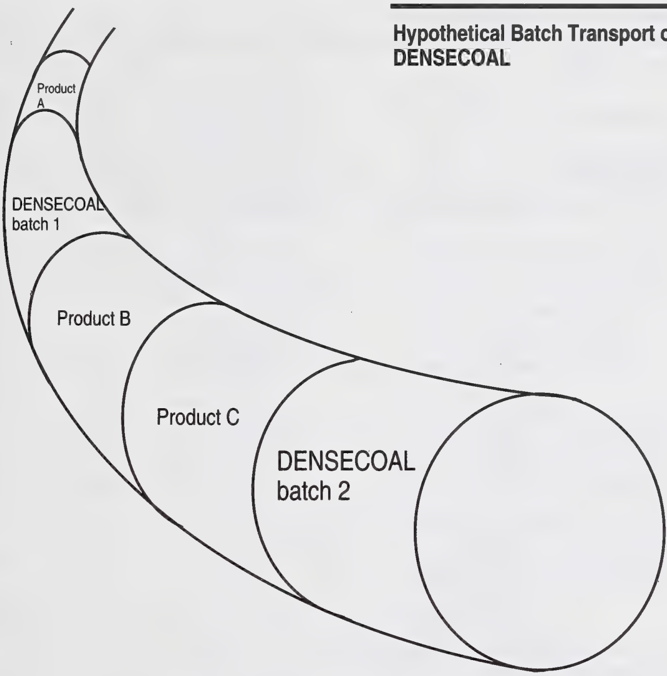
At the same time that CWS technology has been evolving in several countries, new or improved burners have been developed to take advantage of this new fuel. In Canada, CANMET is leading the way in testing and developing burners that are fired by CWS.

In 1982, CANMET demonstrated the preparation of CWS. Subsequently, 6 000 tonnes of CWS were burned in two utility boilers at Chatham, New Brunswick. These boilers were originally designed to burn coal. Then, CANMET participated in projects to test the use of CWS combustion in a compact, 20 MW_e, oil-fired utility boiler in Charlottetown, Prince Edward Island, and a 15MW_{th}, oil-fired package boiler supplying steam for a pulp mill in Hantsport, Nova Scotia. Concurrently, CANMET developed the design criteria for a slurry burner, which incorporated a novel ceramic atomizer fabricated by the National Research Council of Canada. Burners using this atomizer were used in the Chatham, Hantsport and Charlottetown experiments. The characteristics of this CANMET/NRC burner include dual fuel capability (oil or CWS), 30-80 GJ/h capacity, excellent flame stability and little atomizer wear.

Because the CANMET/NRC burner was not available commercially when the Charlottetown study began, design criteria were established for a new burner that could burn CWS and satisfy the needs of the Babcock Wilcox boiler. After an evaluation of burners manufactured by three companies, those made by Coen Burners Inc. of Burningham, California, were chosen for the full-scale test. Five Coen burners were purchased and installed, enough to achieve the 20 MW_e capacity of the boiler.

With these burners operating on CWS, it was found that the atomizer tips experienced some erosion, but after this difficulty was overcome, favourable results were obtained. Good atomization was achieved and the resulting fire was stable with no sparklers. Good carbon burnout was achieved as well. No slagging or fouling in the boiler was observed, and no evidence of erosion on the boiler tubes has been found.

Although studies in test furnaces indicated that the capacity of the Charlottetown boiler might be reduced by as much as 50 per cent when CWS was used, actual operations using the Coen burners showed that the unit could readily achieve 90 to 95 per cent of the full load capacity.



Hypothetical Batch Transport of DENSECOAL

A preliminary design and specifications for a DENSECOAL-P production plant were developed by Salzgitter. These were expanded by Monenco Consultants Limited of Calgary, Alberta. Capital and operating costs were estimated by Monenco for two sizes of DENSECOAL preparation plants: one million tonnes and two million tonnes a year.

These estimates were based on the assumption that a DENSECOAL preparation plant would be located south of Hinton, Alberta, and would receive coal shipped from two nearby mines. DENSECOAL slurries containing 70 per cent solids would be prepared near the mine sites and then be shipped downgrade approximately 90 km to Edson.

A new pipeline having a diameter of 355 mm would be required to connect the CWS preparation plant to the main Trans Mountain Pipeline. At Edson, which is 520 m lower in elevation than the DENSECOAL preparation plant, the slurries would be stored in twelve 5 000-m^3 tanks and then be introduced in batches into the Trans Mountain Pipeline for delivery to a terminal at Vancouver.

At the terminal end of the pipeline, another dedicated tank farm would be used for temporary storage.

Supply Costs of Alberta DENSECOAL*

Capital Costs		Canadian $	US $
Slurry Preparation		37 572 000	31 936 000
Delivery Pipeline		25 038 000	21 282 000
Modifications to Trans Mountain Pipeline		92 120 000	78 302 000
Total		154 731 000	131 521 000
Operating Cost (per tonne CWS)			
Coal (0.7 tonne/tonne CWS)		24.50	20.83
Slurry Preparation		25.51	21.68
Pipeline Toll (transport/store)		18.72	15.91
Depreciation		4.28	3.64
Total	(per tonne)	73.01	62.06
	(per mmBTU)	3.50	2.96
	(per MJ)	3.32	2.82
	(per 1000 kcal)	¥ 1.56**	
Annual Operating Cost (includes depreciation; excludes coal)		$52 037 000	$44 231 000

*Assuming:

(1) the economics of pipeline transportation would be enhanced by selecting the highest possible slurry density that is consistent with pipeline transportation;

(2) the properties of the CWS should result in pipeline rheological characteristics that are similar to those of heavy oil, i.e. a CWS viscosity of 250-300 centipoise at 20 sec^{-1} and 20°C;

(3) coal will be available to the CWS process plant at a cost of US$29.75; and

(4) $1 Can = $0.85 US.

**At currency conversion rates prevailing in 1991.

DENSECOAL Process Plant Specifications

Output Capacity	2 000 000 tonnes/year of DENSECOAL; two parallel streams
Operating Basis	7 560 hours per year; 90 per cent availability
Plant Feed	filter cake or centrifuged coal product from existing preparation plant
Feed Rate	325 tonnes per hour

Trans Mountain Pipe Line Company Ltd. and Interprovincial Pipe Line Company, in cooperation with Salzgitter, produced capital and operating costs for both the western pipeline route to Pacific markets and the eastern pipeline route to the Ontario market.

For the Trans Mountain Pipeline, for example, the modifications necessary to permit two million tonnes of DENSECOAL to be transported were identified. These design modifications were based on the movement of DENSECOAL in 60 000-t batches at a rate of three batches a month.Other products would be sent through the pipeline when DENSECOAL was not being transported.

Trans Mountain Pipe Line Company provided estimates of the capital costs necessary to modify the pipeline and provide the necessary storage capacity at both ends of the line. The estimated costs were C$92 120 000 (US$78 302 000). Also, it was estimated that the tariff required to transport each tonne of DENSECOAL would be C$18.72 (US$15.91).

At various stages of development, the following companies and agencies participated in this project: Salzgitter Industriebau GmbH (now Salzgitter Anlagenbau), Ontario Hydro, Maritime Electric Company Limited, Trans Mountain Pipe Line Company Ltd., Interprovincial Pipe Line Limited, several coal producers, Bundesministerium für Forschung und Technologie (Germany), Energy, Mines and Resources Canada, and the Alberta Office of Coal Research and Technology.

Conclusion

It was concluded that the proposed DENSECOAL system using Alberta coals is both technically and economically feasible. The pumping and combustion characteristics, as well as the economic aspects, of one type of Alberta coal delivered to an Asian market have been established at an experimental scale. Based on the experience the participants have with other fuels, it has been predicted that there would be no technical impediments to operation of this DENSECOAL system at a commercial scale. All that remains is to carry out the large-scale tests necessary to bring cost estimates to the "Class A" level. This would enable decisions to be made about commitments to proceed with commercial-scale operations. This additional testing should be done under the sponsorship of parties who are interested in pursuing the delivery of Canadian coal slurries to Asia as a commercial venture.

It was also concluded that it would be possible for a stabilized form of DENSECOAL to be used by small- or medium-sized combustion operations. Stabilization could be done at the final distribution point, thus avoiding the need for agitators on the customer's premises. For large users, it would be more attractive financially to provide tank farms equipped with agitators, instead of incurring the expense of stabilization. If necessary to satisfy the requirements of a client, it would be possible to reduce the ash content of DENSECOAL to approximately 1 per cent, but this would result in extra cost.

The advantages of DENSECOAL

- DENSECOAL is a highly concentrated, non-polluting and non-toxic suspension of coal, water and additives.
- DENSECOAL can be made from a wide range of coal ranks.
- DENSECOAL flows like oil and may be transported by pipeline.
- DENSECOAL combines the handling advantages of oil with the world-wide availability of coal.
- DENSECOAL is pumped and stored in closed vessels with none of the dust problems that attend the bulk handling of coal.
- DENSECOAL does not present a spontaneous combustion hazard because it does not require coal to be stockpiled.
- DENSECOAL preparation removes most of the ash and inorganic sulphur that are present in the parent coal.
- DENSECOAL can be fired directly in a boiler without treatment.
- DENSECOAL avoids the use of coal pulverizers near a furnace.
- DENSECOAL allows better control of combustion through better mixing with air.
- DENSECOAL allows easier control and delivery of fuel at the burner front.
- DENSECOAL allows the use of more compact furnaces.
- DENSECOAL provides an opportunity to mix sulphur sorbents with the fuel.
- DENSECOAL leads to benign slagging and fouling by ash, and results in lower abrasion by ash.

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Further Information

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ENERGY

ISBN 0-86499-882-1
Pub. No. T/262

Cover photo courtesy of Salzgitter Anlagenbau